FUTURE COMPUTER TECHNOLOGY AND ITS IMPACT

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The digital computer has penetrated many professional specialties and many aspects of everyday life; computing technology itself is entering a new and explosive phase of development. What does this portend for the future?

Let us consider the future impact of computers on society, business, industry, and the military. First, however, it is desirable to call attention to a particular feature of the computer and to one of the ways in which it is used. Second, I want to describe the advance in computer hardware in the 15 years of its commercial lifetime, and the anticipated changes during the next decade.

Traditionally, we think of a computer as a device to do arithmetic. But, as Fig. 1 shows, it is possible to encode other information in terms of numeric symbols. For example, in the telephone dialing system the letters EX are represented by the two digits 3 and 9. This principle allows the digital computer to accept any information that

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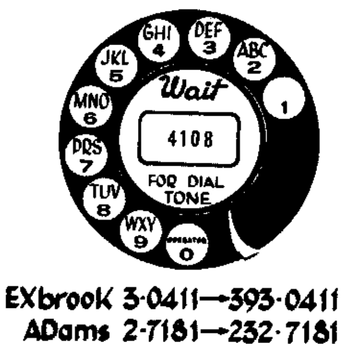

Fig.1

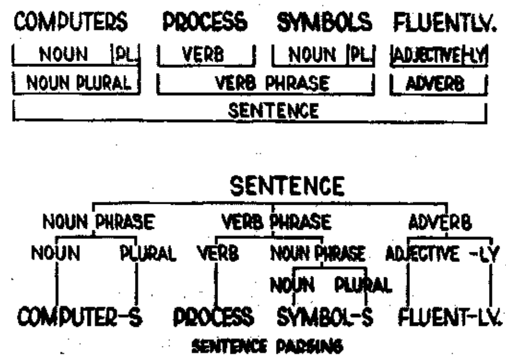

Fig.2

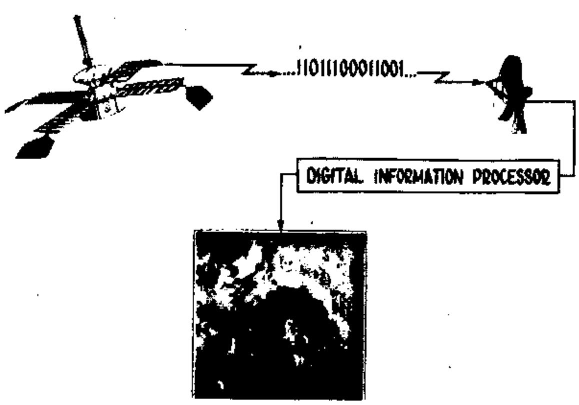

Fig.3

Fig.4

can be encoded in symbolic form. Moreover, by giving the computer special kinds of operations, we can have it manipulate such symbolic information. It becomes an information processing machine. As Fig. 2 indicates, the computer can parse sentences, drawing a picture of the sentence structure. If the symbols happen to be those of algebra, the computer can perform algebraic manipulation. Or, it can process symbolic pictorial information and reconstruct a picture (Fig. 3). We should think of the digital computer as a device that can accept and process any information encoded in symbolic form.

There is a particular way of using a computer called modeling or simulation. Consider a bottle of soda pop (Fig. 4) in which a few chemical radicals and compounds are present. In the mixture itself there are oxygen, carbon dioxide, and other chemical ions. Oxygen, nitrogen, and carbon dioxide are exchanged across the air-liquid interface. We can mathematically describe the chemical activity and the energy balance in this system, and compute its equilibrium state. What we have done is to model a real-life, physical system in terms of a set of mathematical relations.

A model can also be a description of a biological, physical, economic, political, military, financial, physiological, psychological, organizational, or any other system. A model identifies variables in a system and states the relations between them. If the variables of the model and the relations between them satisfactorily represent the real-life situation, then the model is a precise description of the real-life situation. The model

will exhibit the same behavior as that part of reality which it simulates. It can be used to perform experiments; it can be used to explore situations or cases which may be impossible in reality or which we hope will never happen.

Now let's briefly trace two branches of computer hardware development. Figure 5 shows what switching circuits looked like in the early 1950s. Figure 6 represents one form of contemporary circuit technology, the so-called solid-logic construction, containing both printed and deposited circuits. The large elements are resistors (Fig. 7); the small squares at the right of the figure are transistors, 40/1000 in. square. (Transistors are fabricated approximately 600 to the square inch.)

We are just entering the era of integrated circuits. The small square in the center of Fig. 8 is the circuit proper; the rest is mechanical packaging and external connections. The material at the bottom is a piece of thread. Figure 9 shows two examples of an advanced form of integrated circuit technology. A slab of pure silicon is successively doped and processed to form a grid of basic circuit components. The basic background grid (Fig. 10) is a rectangular area about one-tenth of an inch long and one-sixteenth of an inch wide. Such a rectangle contains about 40 circuit elements, of which 30 or so are transistors. By further deposition of conducting and insulating material over the background grid, the customized fully integrated or microcircuit is built (Fig. 11). The postage stamp area about half an inch by slightly over five-eighths of an inch contains a total of about 800 transistors and

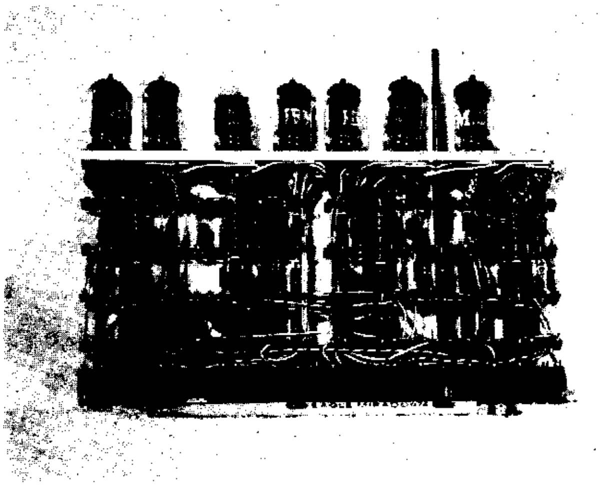

Fig.5

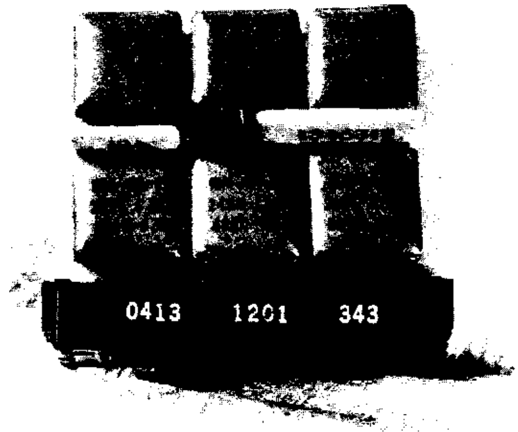

Fig.6

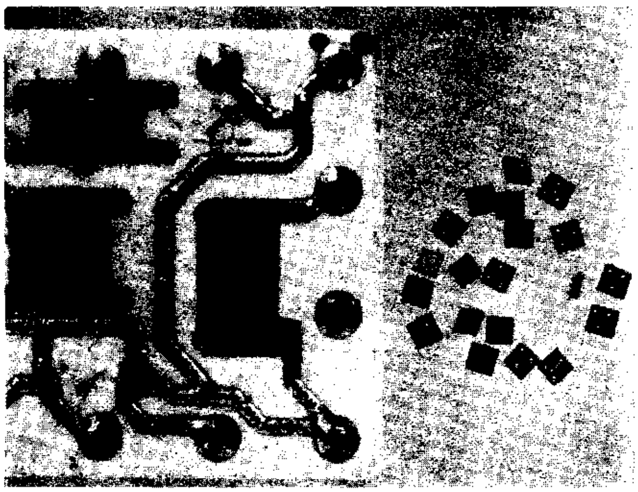

Fig.7

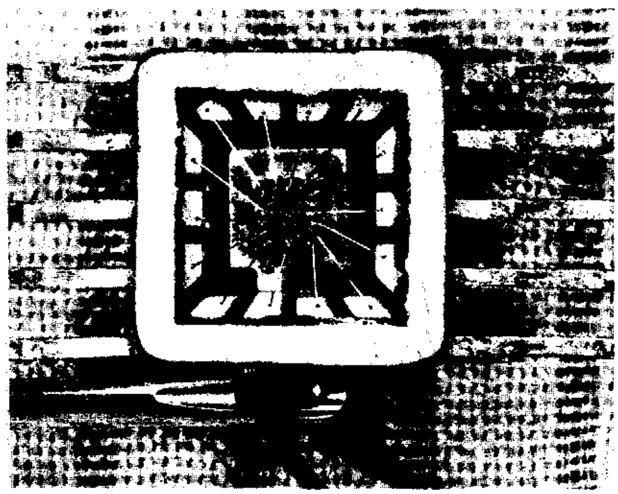

Fig.8

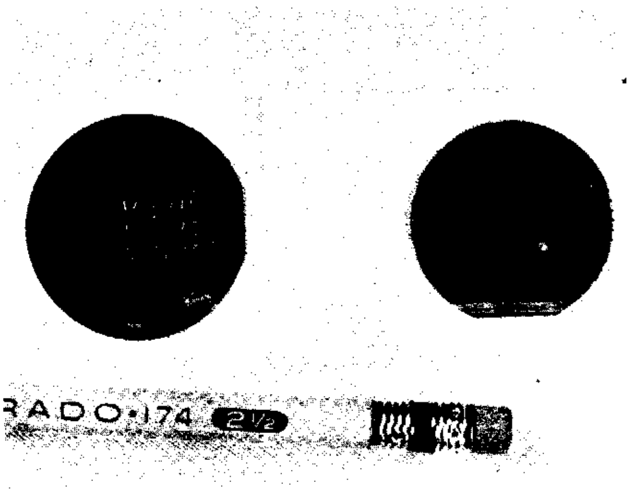

Fig.9

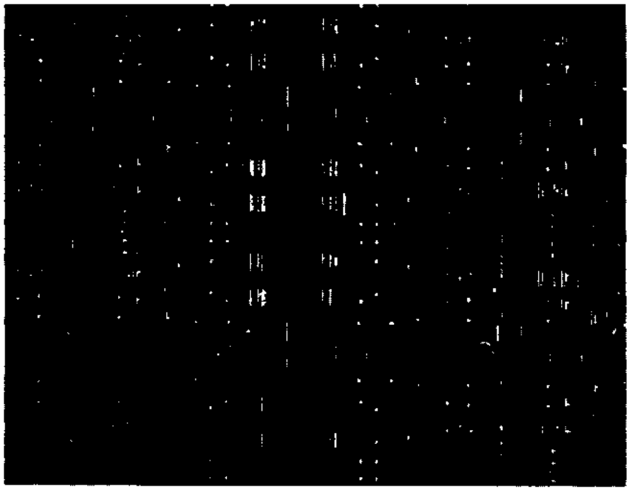

Fig.10

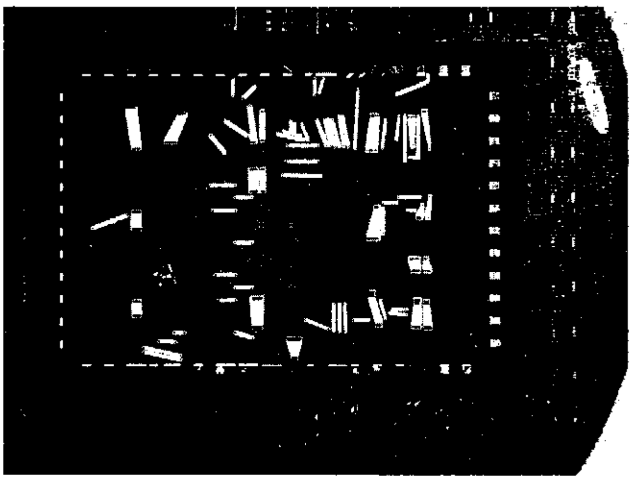

Fig.11

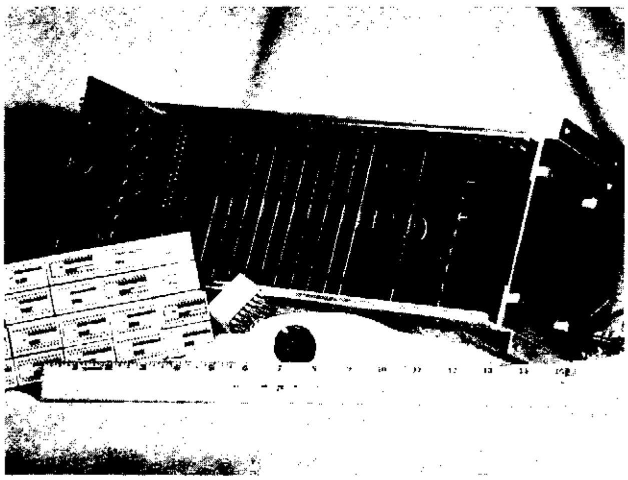

Fig.12

350 circuit components. The packing density in this example is about 3000 circuit elements per square inch. By the early 70s, integrated circuit technology is expected to produce packaging densities of 200,000 circuit elements per square inch, an improvement over present art by a factor of about 70.

Figure 12 shows three generations of circuit packaging. In the background is a contemporary form of printed circuit plug-in packages; in the left foreground are commercially available integrated circuit packages; and, front center is the fully integrated microcircuit. Each represents the same electronic capability.

Let us turn our attention to the storage component of a digital computer. The backbone of storage technology has been and may well continue to be the magnetic core art. Figure 13 shows a large magnetic core plane from the early 50s; the small one in the foreground is contemporary. Each represents the same storage capacity, 4096 binary digits, but the small modern plane is faster by a factor of 15 or so. Figure 14 illustrates the steady decrease in size of magnetic elements used in stores over the years. The final entry on the left is hardly visible, and has been reproduced much enlarged at the right. The tiny X-55 annulus at the top right is magnetic material, seven thousandths of an inch inside diameter, twelve thousandths of an inch outside diameter. Such cores are fabricated into a so-called plane with several wires threading each core (Fig. 15).

The magnetic core store also comes in large economy sizes; Fig. 16 shows one with a capacity of 16-million

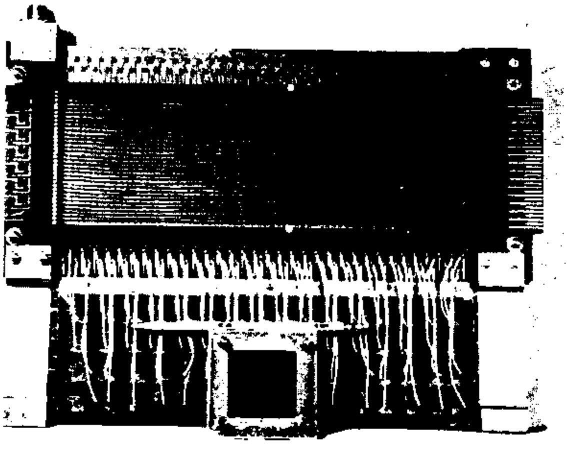

Fig.13

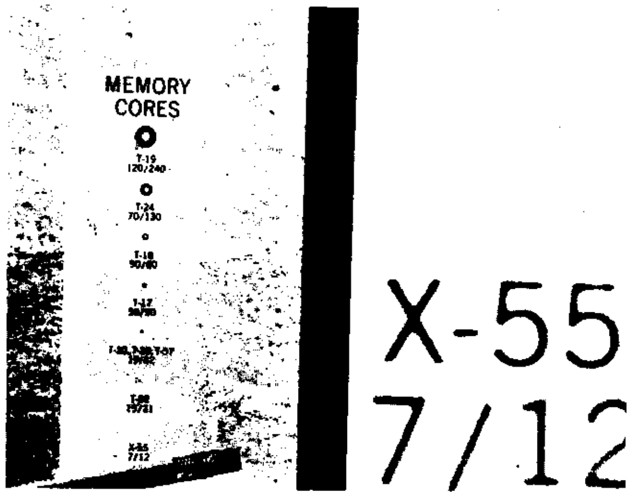

Fig.14

Fig.15

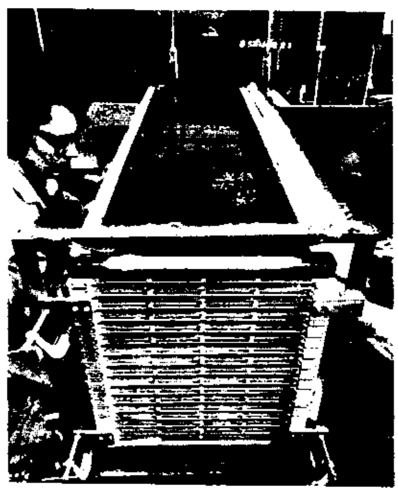

Fig.16

binary digits. Magnetic storage also comes in other forms. Figure 17 is a disc store with a capacity of 60-million binary digits; and Fig. 18, an even larger store with a capacity of about 200-million binary digits.

There are also new forms of terminals enabling men to communicate directly with machines. Figure 19 shows a production model of a personal console which is connected by means of a telephone circuit to a center computer. The entire conversation between the user and the machine is carried on via this electric typewriter. Such personal console stations have given rise to the so-called on-line, time-shared computing system (Fig. 20). Many users scattered throughout a building or over a large geographical area are connected to one or more large, central computers by a communication system. To each user the machine appears to be solely his; but, of course, its enormous speed enables it to circulate among all users, giving attention to each in turn.

Another new terminal is the graphical input-output (Fig. 21), which enables a user to input any kind of graphical or pictorial information and receive the same kind of output. Slide material may also be projected onto the rear of the tablet surface for convenient tracing into the machine (Fig. 22).

Looking briefly at computers over-all, we find that the machine of the early 1950s was typified by RAND's recently retired 13-year-old JOHNNIAC (Fig. 23). Today's typical machine (Fig. 24) is not too much different in external size, but is somewhat cheaper, contains much more hardware and eight times the storage, and is faster

Fig.17

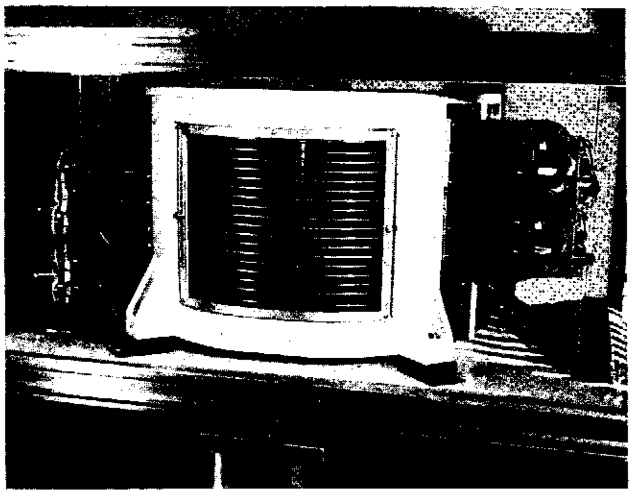

Fig.18

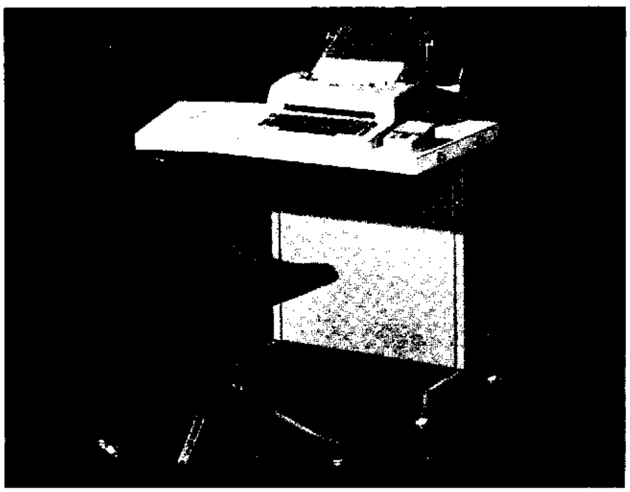

Fig.19

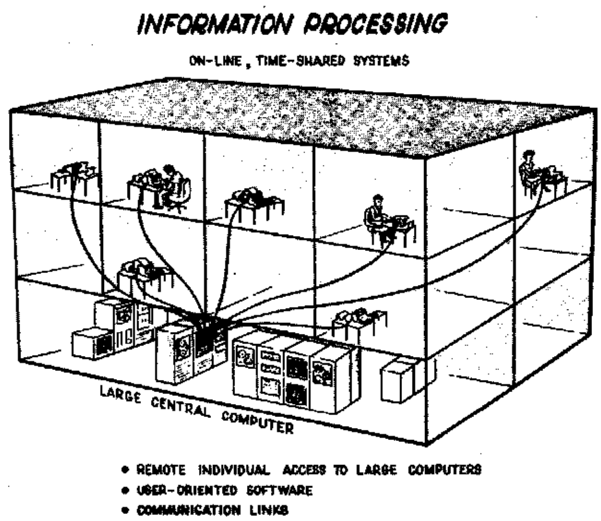

Fig.20

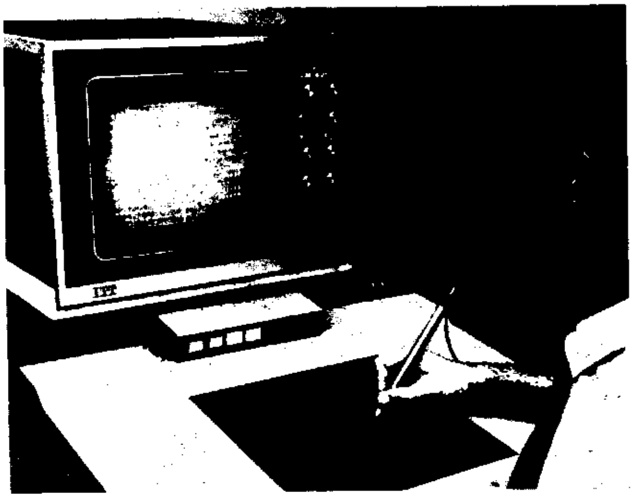

Fig.21

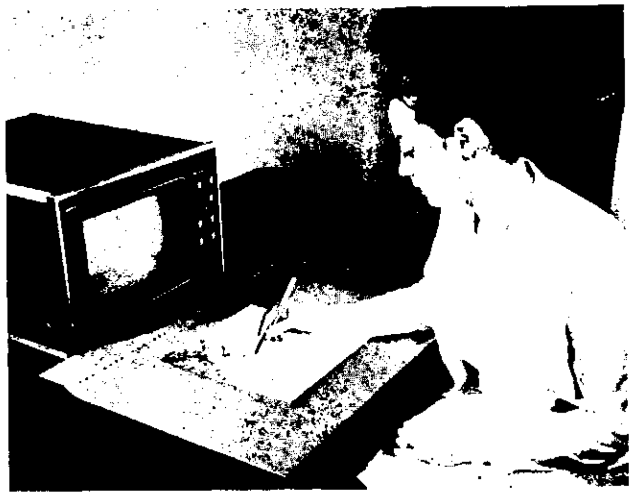

Fig.22

Fig.23

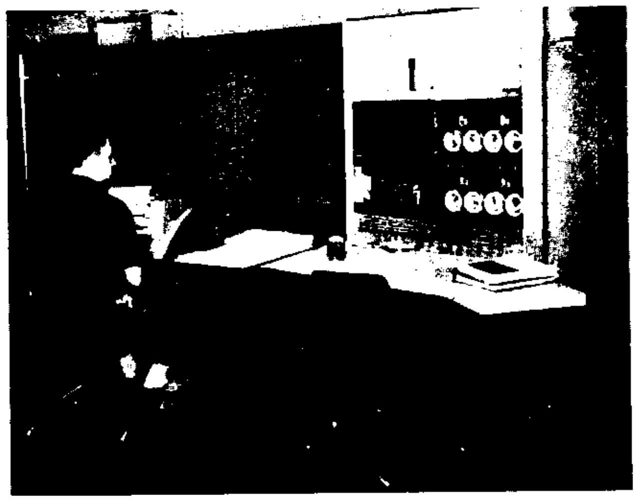

Fig.24

by a factor of 30 to 50. Computers now can be designed to fly in space--e.g., the GEMINI machine (Fig. 25).

We are just beginning to see the introduction of integrated circuits into commercial computers. The arithmetic section of one is shown in Fig. 26; Fig. 27 shows the storage part of the same machine. The complete machine appears in the lower left corner of Fig. 28; the objects surrounding it are various terminal devices for coupling the computer to its environment--a display, a console, a typewriter, and a small magnetic tape unit.

Comparing the old and new computers of Figs. 23 and 28, we find that the 1953 machine weighed about 5000 lb, had a volume of 300 to 400 cu ft, and required about 40 kilowatts of power. The contemporary computer is a hundredfold lighter (about 50 lb), a thousand times smaller (about 1/3 cu ft), and requires 250 times less power (150 watts). Moreover, it has twice the storage and runs about ten times as fast as JOHNNIAC.

We can summarize the amazing progress of computer hardware technology in a few trend charts. Figure 29 shows the change in size.* From 1955 through 1965, the size of a central processing unit with its storage has decreased by a factor of about ten. From 1965 through 1975, the impact of fully integrated circuits is expected to produce a further reduction in size by a factor of about 1000. For the two decades of 1955 through 1975,

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*Figures 29-32 are taken from P. Armer, "Computer Aspects of Technological Change, Automation, and Economic Progress," The RAND Corporation, November 1965.

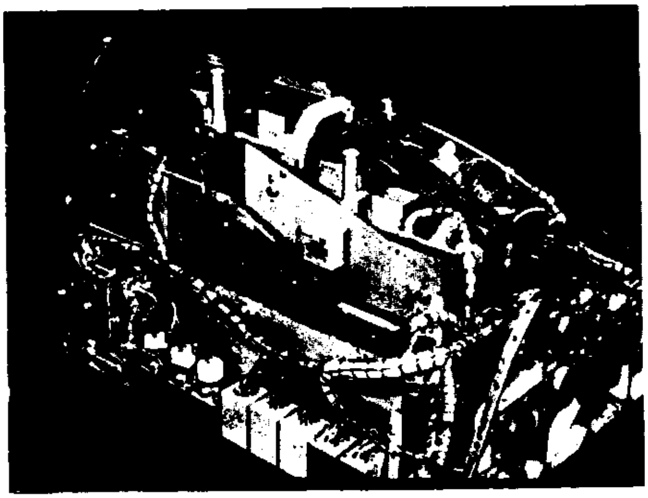


Fig.25

Fig.26

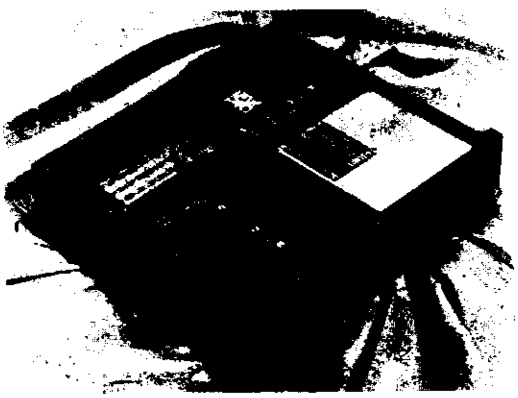
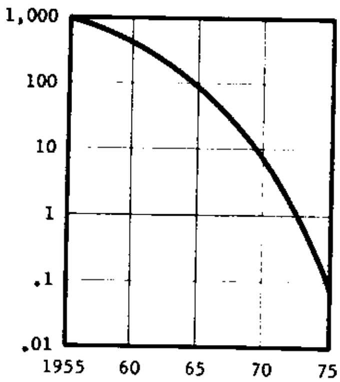


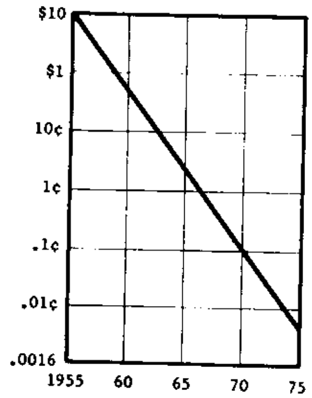
Fig.27

Fig.28



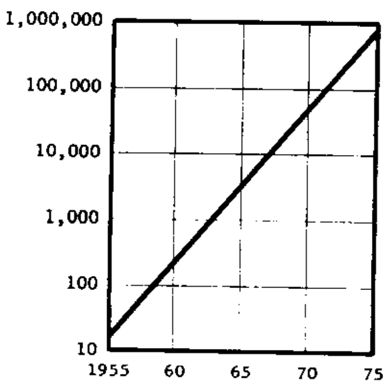
SIZE
CPU/Storage size in cubic feet

Fig.29



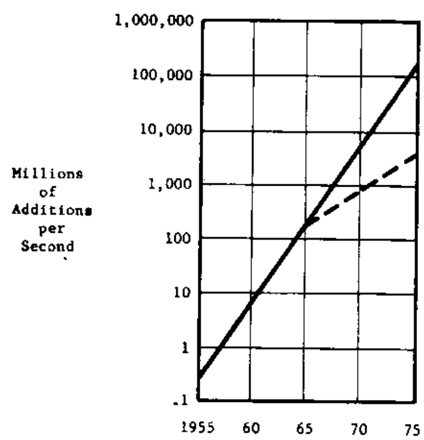
COST
CPU/Storage cost in dollars per million additions

Fig.30



SPEED
CPU/Storage speed in thousands of additions

Fig.31



COMPUTING POWER IN THE UNITED STATES

Fig.32

there will have been a size reduction of 10,000 in the art for building central processing units.

Figure 30 refers to the cost of computing power--not the cost of a computer itself. In the first decade of the computer's existence the cost of doing a million operations decreased by a factor of about 300. By 1975 the cost will decrease by another factor of 300 to less than one 200-thousandth of its 1955 value.

Figure 31 shows how machine speed has changed. From 1955 through 1965 the internal speed of the computer increased by a factor of about 200. By 1975 it is expected that the speed will increase by another factor of 200 or so; so that by the mid-70s, we can look forward to doing computer operations at the rate of about a billion per second.

Finally, let's look at the installed computing power in the United States (Fig. 32). In 1955 all installed computers working together could do about 500,000 additions per second. By 1965 the machine population could do about 200 million additions per second, an increase in capability of about 400 fold. If the same growth rate continues through 1975, capability will increase by another factor of about 400. (A somewhat less optimistic projection for the coming decade still sets the expected growth at 20 fold or so.) The number of computers in the Air Force alone has increased from 350 in 1963 to nearly 700 in 1965.

What does this all add up to? Beginning in the early 1970s, computers will be small, powerful, plentiful, and inexpensive. Computing power will be available to anyone

who needs it, or wants it, or can use it. He may have it by means of a personal console connected to some large central computing facility, or he may own a small personal machine.

We all know, however, that the computer is more than a piece of hardware; it has to be programmed. Historically computer programming has been expensive and time consuming, but we expect the future to be different. Cheap hardware will enable us to consume vast amounts of computational power to make a machine convenient and attractive to a user. Furthermore, with the current or near future state of computing knowledge, we can frame languages including appropriate symbols and syntax which are completely natural to a novice user and to a user trained in any professional specialty. We can design a tool for a given individual from the ground up; a tool to match his normal training and way of thinking.

For example, most automobile drivers don't bother to understand the details of the engine under the hood, or even how the automatic transmission works--such knowledge wouldn't help them to drive better. Similarly, the computer user of the future will not be able to perceive the inner details of the machine, nor would it help him if he could. Communication with a machine is becoming that easy. The new class of users will no more have to be programmers of the traditional kind than an auto driver has to be a mechanic to handle his car.

Such astounding and explosive changes in technology and the growing ease of communication with a computer are almost certain to have a staggering impact. What are some

of the possible consequences of this expected tremendous growth in information processing?

Extrapolating into the future can sound like science fiction, but I hope that my predictions now have a credible basis. My visual summary of the change in computer hardware could be paralleled by a corresponding summary of research in application of computers to new and varied tasks. In particular, we should note the growing capability of the computer with graphical and pictorial information.

Various projections have been made of computer achievements in the 1970s. Let us note one such set of expectations.*

- Computers will be readily available as a public-domain service (but not necessarily as a regulated monopoly).
- Information _per se_ will be inexpensive and readily available.
- Large and varied data banks will exist and be accessible to the public.
- Computers will be used extensively in management science and decision-making.
- Computers will be economically feasible for firms and activities of all sizes.
- Computers will process language and recognize voices.
- Computers will be used extensively at all levels of government.
- Computers will increase the pace of technological development.

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*P. Armer, _loc. cit_.

Let us assume that these expectations have definitely materialized by the mid-1970s, and consider a period further distant. Although some of the suggestions that I will make might arise late in the 1970s, I want to pick a time more remote; let us consider the mid-1980s, perhaps the Orwellian year of 1984.

I am not making predictions, but rather I am suggesting things which in my opinion computer technology can make possible. Whether these suggestions actually materialize into fact will depend, of course, on many other things--such as political, social, and economic forces; rate of capital investment, rate of production, etc. The computer will contribute to our future in two ways: a) it will make some things possible because of its capability as a research tool; b) it will be an integral and operational part of other systems which without the computer would have been impossible. Behind everything I suggest stand the assumptions which I hope you now readily accept: computers will be inexpensive, small, powerful, and plentiful; modeling will be a powerful technique; the computer as a tool will be a user-oriented device.

I must at least touch on the issue of general social impact first. The computer is helping technology to move so swiftly that professional skills rapidly become obsolete and large blocks of employment openings disappear from one industry to reappear in another. Frequent retraining and re-education is likely to become the normal way of life. Change, not <u>status quo</u>, will be everyone's lot--in civilian as well as in military careers.

As we shall see, the computer can assist people in adjusting to this new state of affairs. Certainly the introduction of computers into industry will improve productivity, but will dislocate jobs. It is easy to believe that men will be without work. However, I am partial to a more optimistic view. The computing industry per se is creating new jobs, as well as moving old ones to new places. The wants of society are not now being met, and even with the increased output from the economy that better productivity can bring, plenty of jobs will probably be available, although they may not be in the "right" places. We must face and solve the retraining and re-education issue, a problem which will not be limited to the labor force. Each professional specialist or administrative official faces the problem of continuous re-education and adaptation as well.

By the 1980s, the use of the computer as a teaching machine will have increased the entire pace of education. It is an ideal device for exercising, instructing, and examining students on a large amount of material. Sophisticated training films produced by computers will give students deep, rapid insight into physical and scientific problems.*

Students will have computational power available to them wherever they may need it. The public school systems and universities will have to provide each student with

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*For example, the Bell Telephone Laboratories has produced a twenty-minute film--Force, Mass and Motion--by computer, which gives great insight into gravitational laws.

computational support, either as a personal console connected to a centralized large computer or as a small computer of his own, perhaps the size of a small cereal box. Parenthetically, in most homes I foresee a personal console (or small machine) for use by the entire family--it will be in effect another appliance.

With the increased pace in education, students are likely to complete their formal schooling much sooner; alternatively, they will acquire more training in the same time. Consequently, everyone will have more productive capability, which in turn will speed up technology and science. There may be an even more overwhelming effect: if it is true that youth is an important aspect of scientific creativity, the increased pace of education will result in more young productive years.

The rapid changes in technology caused by the computer tend to make technical skills obsolete, but the computer will help to alleviate the very situation it is causing by making possible not only rapid re-education and refurbishment of technical knowledge, but also swift acquisition of new skills.

For example, in the Air Force, manpower skills will be developed more rapidly; an officer should achieve a much higher level of technical competence much earlier in his career, and be able to refresh his abilities readily. By means of models we can exercise him in a variety of situations, and so sharpen his judgmental ability much sooner. Similarly, the computer might be exploited as a training device in military aid programs to improve the technological skill level in underdeveloped countries.

By the 1980s, I expect the tempo of scientific discovery to increase. I previously granted that the pace of technology will increase; I now refer to the acquisition of new scientific information. Computers will allow data to be displayed in ways not otherwise possible; they will let the scientist observe situations which he could not otherwise examine.

The computer will be the most important tool ever available for the conduct of research. Sophisticated mathematical and simulation techniques will be widely exploited for many situations and systems which scientists would not otherwise be able to study; e.g., solving mathematical models of the atmosphere and displaying the results as motion pictures in order to study weather patterns in a vastly speeded-up time scale. Such a capability would be a valuable adjunct to Air Force operations.

In the future, experimentation by computer will be less expensive than other methods, permitting scientific investigations otherwise impossible. In fact, I would not be surprised to find laboratories tending to go out of style. The man-and-his-computer may well rank ahead of the man-and-his-laboratory as the source of new scientific knowledge. I foresee a future in which the principal function of the laboratory is to validate computer models. The quickening pace of scientific investigation will mean new capabilities, new materials, new technologies, and new tools for the Air Force.

Because vast quantities of information will be transported from place to place, there will be an enormous demand for communications services. The communication

networks, however, will have become totally digital; no longer will we transmit analog voice or video signals. Cheap digital components will allow the use of sophisticated techniques for removing redundancy from signals before digitizing and transmitting them. When error-free transmissions are important, controlled redundancy will be reinserted into the messages. It is reasonable to expect that all transmissions will be encoded and hence private. I can foresee that all the voice, video, facsimile, and data transmissions needed by a place of business-or a residence--will be handled digitally over a broadband cable.

We can expect to know <u>how</u> to modify and to control weather, although we may not have the large energy sources required for a <u>working system</u> of weather control. The computer will have made this possible, because of the general increase of knowledge which it will have supported and the understanding of atmospheric physics achieved through modeling and simulation techniques. If we achieve a working capability for weather control, the consequences will be measured in the billions of dollars. Universal good climate will eliminate bad real estate. The Nevada-California deserts could become the breadbasket of the United States. Crop failures will vanish because sunshine will occur in the right amounts at the right times. "Weather Central" will arrange the storms and probably even publish an annual schedule of rains and snows. The weather schedule will be as well known as the dates of holidays; one may well buy it at the Government Printing Office for a nominal sum. The ability to control and

modify local weather is obviously important to Air Force operations.

I foresee that our entire engineering design process will be computer-based. By means of graphical terminals, the engineer will be able to converse directly with his machine. He will sketch only the roughest outlines of a design and let the machine provide all details. Before the device is built; the machine can exhaustively test it for him by calculating and simulating its performance. Engineering drawings will be unnecessary; the blueprint will be replaced by (say) a roll of magnetic tape containing all the details for automatic fabrication tools.

The medical and biological sciences will probably use the computer more extensively than the physical sciences. Hospitals will have become completely computer-supported in medical as well as business and administrative aspects. Because they are cheaper and more accurate, computer models will handle most laboratory work. A computer will be connected to surgical patients in order to monitor body processes and to warn of dangerous incipient conditions. Consequently, much more daring surgical and medical procedures will be used. For example, a computer analyzing electrical activity of the brain can regulate the positioning of microelements for brain surgery. Similarly, computers will be used to control prosthetic devices. Post-operative or intensive-care patients will also be monitored by a computer.

Even more dramatically, the increased pace of scientific discovery owing to the use of the computer in research may contribute to the extension of the human life

span. Through computer analysis and experimentation with enzyme structures and with the basic building blocks and codes of proteins, we may learn how to synthesize specific enzymes, which will make possible the growth of new body parts or organs, or the revitalization of an entire body by causing it to resume growth. In fact, if we learn enough about enzymes and body building blocks, we ought to be able to grow an organism to specification.

The implications of a significant increase in human life span are overwhelming. The population explosion problem would be enormously more important. Industries based on mortality tables might not survive. Other organizations would have to find new advancement opportunities for young people, since present employees would have a longer productive life. All such changes would certainly affect religious and social patterns.

The possibilities in medicine and biology have consequences for the Air Force. The computerization of hospital functions also applies to field medical operations--keeping track of patients, keeping records on medication, monitoring patients for dangerous conditions, etc. Perhaps medical treatment might even be computer based or even computer controlled. Moreover, body behavior in unusual situations or in novel vehicles can be studied through models.

It has been forecast that by 1975 the files of information which society needs to govern itself will be computer based. I refer to information on real property, credit status, legal status, financial status, licenses, and so on. In view of population increases, government

will have to depend on the computer. Hopefully, this will make the government more efficient but less expensive. Because of the computer's ability to accept and correlate information from the many large data banks and files which will exist, there will be possible an intensive social and personal surveillance by any agency that elects to do it. The depth of surveillance may well surpass simple invasion of privacy.

A criminal activity data bank is one such information file that will undoubtedly exist. Even today, the computer is beginning to contribute to the control of crime by rapidly retrieving information from files. The future role of the computer is bound to grow as its data banks expand and as it becomes better at making inferences from fragmentary factual information. A machine will be able to provide much more incisive indictments about crimes and criminals. Moreover, for each case it will undoubtedly recommend a treatment for curing rather than impounding the criminal.

Remember that in the future computing power will be readily available to everyone, either as a small personal machine or as a personal console. The computer will certainly be useful to society in combating crime. But might it not also help the criminal plan his crime or the large criminal organization manage its affairs?

Certain implications of future computer technology will be peculiar to the Air Force. Without a doubt, any officer or enlisted man who can use it can have computing power. If necessary, we will be able to build a machine the size of a cigarette package. As in civilian life,

all communications will have become digital, making computer technology an integral part of communication equipment. Everyone can have private communications by using a small personal computer for scrambling. The individual may be permitted to use communication satellites; his personal computer will assemble the message, encode it, handle the error-control problem, provide secrecy, etc. We can provide voice, video, facsimile, and data transmission to individuals as needed--in each case, with privacy. Computers with wideband data links can provide graphical communications, allowing widely separated Air Force elements to discuss plans, documents, maps, etc., as though they were in private conference.

We are currently hearing discussions of control of general war. It seems to me that no enemy will believe that the United States can control a general war unless he sees, among other things, a credible and tight command and control system that is well-trained and regularly exercised. In fact, in the spectrum of possible deterrent mechanisms, I believe that a computer-based command and control system could be a credible deterrent--just as weapons are.

On this next suggestion I am less certain of the time. I suspect that it's ten or twenty years further away than anything I have touched on so far--close to the end of the century; it is perhaps the most dramatic effect that computer technology could have on the Air Force: Computer technology may make obsolete traditional warfare--warfare in which destructive energy is delivered on an enemy by weapons. Let me suggest a plausible argument to

support this conjecture. Twenty or thirty years from now we'll have all the computational power that we can possibly use, so the computer _per se_ will be no problem. By that time we should also be extraordinarily proficient in modeling. In particular, we should be able to model in detail any segment of the world's political or economic situation--in particular, the status of what we would now call the enemy. Presumably he will be able to do likewise against us. I foresee the possibility that warfare will be a series of political moves and countermoves backed up not by exchange of military attacks as in traditional warfare, but by the manipulation of an enemy's external environment (e.g., the economy of other parts of the world) or even his internal environment (e.g., his weather). One might even argue that warfare could become an exchange between your model of the enemy and his model of you.

If something such as I have suggested were to come true or even partly true, the role of the Air Force would certainly change. What might be its role in such a world? Perhaps the Air Force would become a professional arm of the government, as the Army Corps of Engineers presently is the professional construction arm of the government. Perhaps the Air Force would become the professional explorer or adventurer for the government--perhaps the explorer of space. Perhaps the Air Force will continue to fight a traditional warfare, but in outer space or on another planet. Perhaps the Air Force will be the executive agent to deliver energy to the atmosphere to achieve weather control. Whatever, the role of the Air Force will change.

I've suggested several possible impacts of the computer. I've not detailed any of them, but I hope that I have shown each to be credible. Many of my suggestions have important sociological implications and challenges; I have acknowledged but not explored the interaction between technological possibility and political, economic, and social factors. My case for believing that these events can come about rests on these points:

- Computer hardware will continue to increase in speed but reduce in cost and size.
- The computer can process all kinds of symbolic information.
- The technique of modeling allows the computer to simulate and experiment with all kinds of systems and situations.
- We are solving the programming problem.

Dr. William Baker of the Bell Telephone Laboratories has characterized computer technology as a question; I know of no answer to it:

> What other technology is there in which the United States has such a commanding lead, which will have as much effect on how we design and do things, which will be as pervasive, and which will both attract and appeal so strongly to the young mind?

This brings us to the end of our tour through Computerland. I hope that I have enlarged your image of the computer or, as we ought to call it, the information processor. It is the most powerful and most flexible tool ever available to man and to society. It is not a replacement for man in any large and encompassing sense; it will displace him in many jobs, but it also will offer

him many new opportunities. The computer will touch men everywhere and in every way, almost on a minute-to-minute basis. Every man will communicate through a computer whatever he does. It will change and reshape his life, modify his career, and force him to accept a life of continuous change.